·Review·

Serious games in science education: a systematic literature review

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Abstract Teaching science through computer games, simulations, and artificial intelligence (AI) is an increasingly active research field. To this end, we conducted a systematic literature review on serious games for science education to reveal research trends and patterns. We discussed the role of virtual reality (VR), AI, and augmented reality (AR) games in teaching science subjects like physics. Specifically, we covered the research spanning between 2011 and 2021, investigated country-wise concentration and most common evaluation methods, and discussed the positive and negative aspects of serious games in science education in particular and attitudes towards the use of serious games in education in general.

Keywords Serious games; Simulations, Artificial intelligence, Virtual reality, Augmented reality; Games in education

1 Introduction

Video gaming is currently one of the biggest industries in the world, and it generated approximately $114 billion in 2020[1]. Thanks to advancements in graphics quality and network speed, the gaming industry spurred from early 2000, and since then, the revenue is steadily increasing. Additionally, big franchises organize online gaming events, and the number of participants is rising. A graphical depiction of global revenues of the video game industry from 1971 to 2018 without considering the inflation is shown in Fig 1. The time and effort put in by gamers are considerably high. Modern technologies have a significant impact on every industry, including gaming and education; it is crucial to see how science education has improved under its shadow and how it relates to gaming. Over the years, research studies on the impact of games on educational purposes have grown. They all point to the same conclusion: a game-based learning strategy has a more significant influence on people, especially children[2]. Science education teaches science to school children and non-scientists, and the gaming industry has encouraged its growth by developing

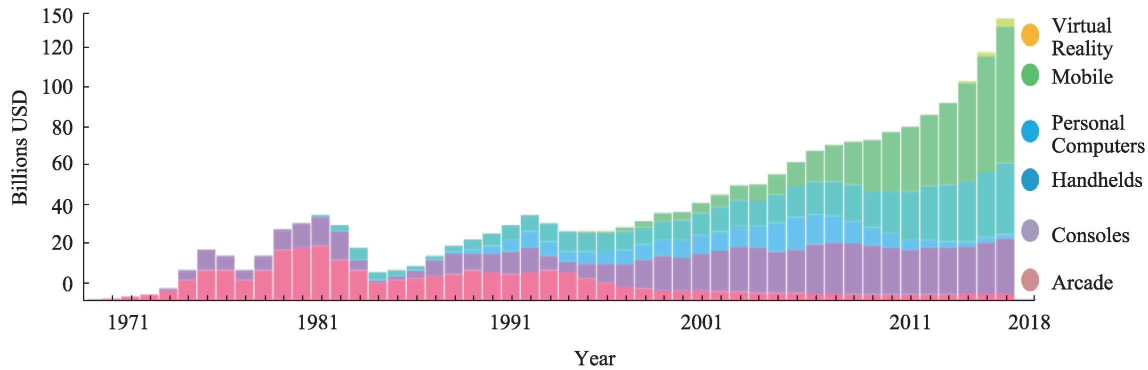

Figure 1 Global revenues of the video game industry from 1971 to 2018, not adjusted for inflation[40].

serious games.

Serious gaming is the use of games to fill needs other than just entertainment[3,4]. Serious games are also called applied games, and this concept of gaming is used by industries like defense[5], health care[6], emergency management[7,8], education[9], sports[10,11], exploration[12], city planning[13], engineering[14], and politics[15]. In addition to this, computer vision and deep learning-based techniques can be exploited in a gaming context to analyze performances of sports players through tracking[16–19] in a virtual environment[20,21], detection[22–24], analyzing anomalous behavior[25–27], simulating individual[28,29] and crowd behavior[30–35] for public infrastructure design[36,37], and a variety of other multimedia applications[38–40].

In one part of this review, we discuss how education uses serious gaming to help children with an improved learning experience with the help of some real-world examples, including games like around and around and other games from science kids and science seekers. There is no doubt that the vast prosperity of the gaming industry is because of the exciting combination of the concept of play and technology. A considerable percentage of video games players find it to be an extremely pleasurable experience. Not just that, they are willing to invest a massive amount of time and effort in playing them[41,42].

1.1 Serious games in science education

Teaching science with computer games and simulations goes back to the 1970s and early 1980s, where the ability of games and simulations has been widely explored as a new teaching method[43]. In the early 1990s, the first communication and information technology games to investigate scientific and technological aspects were created[44]. Figure 2 shows the relationship between games, video games, serious games, and serious educational games. At the start of the millennium, the value of commercial video games in science education has risen, as has been the case with the development of serious games with scientific subjects such as chemistry, physics, and biology[45]. Furthermore, correctly displaying abstract ideas and critical principles of given topics in the game environment, increases students' motivation[46], enhances knowledge acquisition[47], and promotes specific abilities like critical thinking, problem-solving, and encourages collaborative effort[48]. For example, A recent pilot study

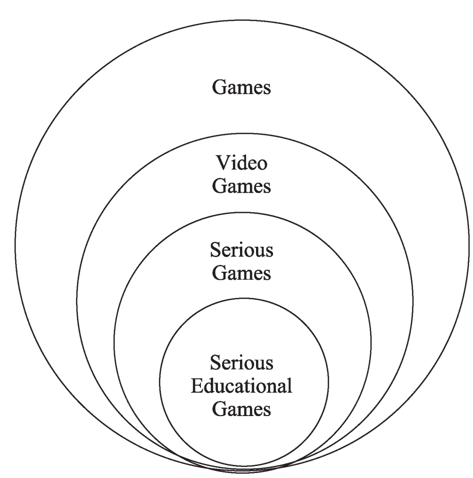

Figure 2 The relationships between games, video games, serious games, and serious educational games[38].

conducted in 2021 by Graeske et al.[49] shows that implementing VR-based teaching tools boosted students' motivation by increasing possibilities to co-create, co-design, and customize their learning. Additionally, it enhances students' problem-solving skills in upper-secondary school. A comprehensive list and brief description of recent review papers on the use of serious games in education is given in Table 1. Similarly, a study carried out in 2014 at the ILD Lab at Aalborg University, Denmark, categorized the science games in their research projects into five different categories as follows[50].

- Training games
- Inquiry games
- Professional simulation/epistemic games
- Embodied system games
- Research collaboration games

Table 2 shows the example of serious games in each of the above-mentioned categories.

1.2 Simulation-based augmented reality games in physics

In 2016, the GPS-based augmented reality (AR) game "Pokémon Go" captured the attention of the whole world from young to old. In just over two weeks, it secured a fan club and active users of size over 20 million[51]. It became the top game-winning on Twitter and Facebook over daily active users and on time spent per day, respectively. People started going outside and socializing to find virtual monsters and gain points. The most common effects of AR learning games are improved learning performance and a more enjoyable learning experience in terms of joy, excitement, and happiness[52]. For example, in 2021, Christian et al. explored Microsoft HoloLens to teach the three-dimensional structure of human organs systems and structure to physiology and anatomy students[53]. A similar study was also conducted using the handheld table. It was reported that HoloLens causes dizziness. However, other than that, there were no side effects like nausea, disorientation, or fatigue. It was concluded augmented reality-based techniques can be used in health sciences and medicine with any serious side effects. Augmented reality can show an image, information, buttons as an addition to the reality that helps to analyze interact or understand what people see on the screen of glasses or smartphones. Interactivity and smooth integration to the real-world make Augmented reality one of the most promising technologies of our current world. We reviewed two experiments like the impact of usability on motivation in AR serious games[54] and physics-simulated serious games[55]. Analysis and results are based on the evaluation of elementary, middle, and high school teachers and students.

1.3 Research questions

In this study, we thoroughly examine the previous studies and serious games developed for the advancement of science education from 2011 to 2021. To this end, the following four main research questions are addressed:

(1) Which journals and conferences are more focused on this field?

(2) What is the year distribution of articles?

(3) What is the country-wise distribution?

(4) How the intervention of serious games in science education is evaluated? e. g., administering a questionnaire to students/teachers, interviews, on-site observations, and recordings, etc.

The paper is structured as follows. In section two, we describe the background and the evolution of serious games in science education. The role of augmented reality in serious games is elaborated in section

Table 1 A comprehensive list of recent review papers on serious games

Authors	Title	Description	Year
Noroozi et al.[56]	A systematic review on the impacts of game-based learning on argumentation skills	This review paper maps instructional support and learning outcomes of argumentation game-based learning. It highlighted that modeling, reflection and feedback were the most reported instructional support of argumentation game-based learning. Feedback, challenge, and collaboration were the most reported game elements of argumentation game-based learning. It concludes that a high level of argumentation skills and engagement were the most reported positive learning outcomes of argumentation game-based learning.	2020
León et al.[57]	Between Level Up and Game Over: A Systematic Literature Review of Gamification in Education	This review paper examined the existing evidence on the impact of educational gamification on student motivation and academic performance in the last five years and analyzed its distribution over time, educational level, variables, and most used game elements, and know the advantages of its implementation in the classroom. It concludes that educational gamification has a potential impact on the academic performance, commitment, and motivation of students.	2021
Cheng et al.[58]	Affordances of Augmented Reality in Science Learning: Suggestions for Future Research	This review paper identified two major approaches of utilizing AR technology in science education, namely as image-based AR and location-based AR. These approaches are reviews in the context of affordances for science learning.	2013
Hafsa et al.[59]	Learnability factors of AR usage performance: Validating through survey	This review paper identified seven factors that influence the learnability of AR usage in education. Survey method was used to validate the identified factors (Motivation, Better lab experience, Enhanced Focus, Satisfaction, Enable Visualization of Invisible Concepts, Better Learning and Performance and Confidence) and on average, the results showed an acceptance rate of 94% within the proposed learnability enhancement model (LEM).	2021
Kamińska et al.[60]	Virtual Reality and Its Applications in Education: Survey	This survey paper present new opportunities in VR and put together the most interesting, recent virtual reality applications used in education in relation to several education areas such as general, engineering, and health-related education. Moreover, it proposed different scenarios for testing and validating the VR approaches in education.	2019
Lamb and Elizabeth[61]	Virtual Reality: a Tool for Preservice Science Teachers to Put Theory into Practice	This study investigates, compares, and characterizes interactive VR-based preservice science teacher clinical teaching environments with those of real-life teaching environments. The study concluded that the main effect of the VR condition versus real-life was not statistically significant in terms of the retrospective engagement survey, psychological measures, and composite neuroimaging. Therefore, the use of VR, in terms of the realism of the environment for the preservice science teachers may allow them to learn from modeled real-life situations for the transfer of skills from VR to classroom use.	2020
Agbo et al.[62]	Application of Virtual Reality in Computer Science Education: A Systemic Review Based on Bibliometric and Content Analysis Methods	This survey paper investigated the role of virtual reality (VR) in computer science (CS) education over the last 10 years by conducting a bibliometric and content analysis of articles related to the use of VR in CS education. It highlights that the VR research for CS education has gradually increased since 2011. It concludes that even though scholars are leveraging VR to advance CS education, more effort needs to be made by stakeholders across countries and institutions.	2021
Tilhou et al.[63]	3D Virtual Reality in K-12 Education: A Thematic Systematic Review	This review paper examined three-dimensional (3D) virtual reality (VR) in K-12 education from 2010 to 2019. The study highlights that 3D VR is commonly applied in middle and high school science classrooms and facilitates the pedagogic approach of inquiry-based learning (IBL), which is a branch of constructivism. It concluded that 3D VR technologies leads to enhanced learning experiences, leading to increased achievement and motivation in students of all age group.	2020
Kalogiannakis et al.[64]	Gamification in Science Education. A Systematic Review of the Literature	This review paper presents the empirical findings of the state-of-the-art literature on the use of gamification in science education. It highlights the latest emerging trends of gamification in science education while revealing the literature gap, challenges, impediments, and extending the possibilities for future research directions. The paper examines the conflicting findings of other studies and provides a framework and insight for future researchers regarding content areas, educational levels, theoretical models, outcomes, methodologies, game elements, and assessment tools	2021

Table 2 Categorization of science in research projects at the ILD Lab at Alborg University. The games listed in parentheses were not covered by our research[44]

Science game Category	Game learning goals and activities	Game research examples
Training games	Designed to train skills through repetition of an individual exercise, e.g., training basic math skills or the composition of chemical compounds	MateMaTris, (other game examples outside our research: DragonBox)
Inquiry games	Focus on scientific inquiry; can involve data collection processes, verifying hypotheses and generating theories or building scientific arguments	Homicide (Quest Atlantis)
Professional simulation/ epistemic games	Gamer's role plays scientific or technical professions and conducts authentic practices, e.g., as forensic detectives or urban planners	Game-based innovation Homicide (Urban Planer)
Embodied system games	Focus on experience and manipulation of scientific phenomena; center on, e.g., atomic models or electromagnetic forces	Quantum Moves (Supercharged, Newton World)
Research collaboration games	Participation in real high-level scientific research and technical development, e.g., in scientific discovery games designed to help real-life scientists solve authentic scientific challenges	Game-based changing of unsafe urban spaces Quantum Moves

three. A detailed description of inclusion and exclusion criteria, research methods used in related studies, and their systematic map are given in section four. The complete description of the results is given in section five. The conclusion, current trends, final remarks, and future works are discussed in section six which concludes the paper.

2 Background

This paper reviews the work done on serious games to improvise science education. Historically, the definition of serious gaming is only restricted to "a game designed for learning and education" but the definition has grown and achieved a broader perspective since then. In the contemporary world, science education along with serious gaming covers a huge ground. This includes some basic subjects for example sociology, psychology, anthropology, biology, political science, economics, and public policy. Other areas covered by serious gaming include engineering, architecture, mathematics, and information science. However, this paper restricts talking about science education and how it has improved through serious gaming over the years.

The level of interest in creating modern and creative learning resources has grown steadily in previous years. Video games for instructional purposes have slowly gained more focus from educators and scholars, and the positive effect of video games on learning has appeared increasingly encouraging[38,48,50,51]. Notably, for science education, the use of video games improves science studying has progressively become prevalent since the Serious Gaming Movement was launched in 2002[52,54-65]. Experts also believe that serious games can be an essential and versatile resource for science teaching because of their unique ability to mix serious subjects with entertainment[66].

2.1 Empirical studies on serious games in science education

Research conducted in 2014 reported the review of empirical research on serious gaming from 2002 to 2013. The researchers identified the keywords they used to find the work they studied to conduct their research. They used the SSCI and SCI databases to find the relevant work published in journals. They continued by iteratively going through these articles and involving in a discussion. These education researchers focused on three dimensions; the pedagogical approach in the game, the research method used, and the game itself. There was a detailed explanation of how every dimension is used and applied in the game, for example explaining what the pedagogical concerns of the game are, the research concerns, and how the game works. The results of the game dimension showed the most popular journals for games, followed by the most reviewed category of games which in this case was adventure and role-playing games.

The results were further categorized by whether the games were single-player or multiplayer. It was also shown that out of 53 games reviewed, 45 were for science education, while the remaining eight were for non-science. Apart from this, the gaming dimension concluded the results in 7 more categories. Further in the paper, the results of the pedagogy dimension were shown, it was categorized according to most taught science domains in the games. Other categories of results were theoretical foundations, Instructional strategies, and pedagogical roles. The learning environment was the most important pedagogical role used in the years mentioned. Finally, the results of the research dimension for the mentioned journals were categorized according to the most targeted audience by the games, which in this case was pre-school students. Research methods and research foci were the other two categories where charts were led by quantitative research and cognitive outcomes respectively. It is concluded that the term serious game has evolved as the number of studies covering it increases and so does the number of games[67,68].

2.2 Enhancement of serious games in science education over time

An article published by ENVRIplus in May 2016 talks about how serious gaming is an improved, and user-friendly way of attracting students towards education and learning. ENVRIplus is a research center working on multiple domains, one of these domains includes serious gaming. They talked about how the game they are developing will specifically focus on science education. They are training student scientists to research different infrastructures for the project. This was also a competition between students as to who contributed the most to the project, so this project was practicing a way of serious game, to conduct research on serious gaming. The game is now playable on the ENVRIplus website[69].

2.3 User of serious games in science education for children

In the domain of serious games, some games are available for children to learn basic intuition about nature. One game that has helped children to learn about plants is "how to grow a plant"[70] shown in Figure 3. In this game, children learn how much sunlight and water does a plant need to grow. They must balance it out so that the right amount of water and sunshine is provided. In this game, they try to grow a perfect plant in different conditions. Another game that helps children learn about science education is melting points[71] shown in Figure 4. In this game, children learn about the melting points and boiling points of different objects. They can heat and cool items under different temperatures. They learn at what point do things like chocolate, aluminum, candle wax, butter, and ice candy melt. All this stuff is helping them learn more science stuff. Figure 3 and Figure 4 shows that the games have a straightforward user interface as the purpose is to help children enjoy and not complicate the games as well, and by playing the game, they are also increasing their knowledge.

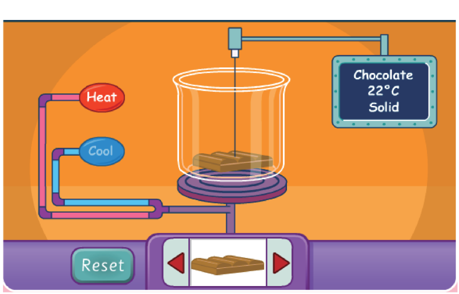

Figure 3 How to grow a plant Game[56].

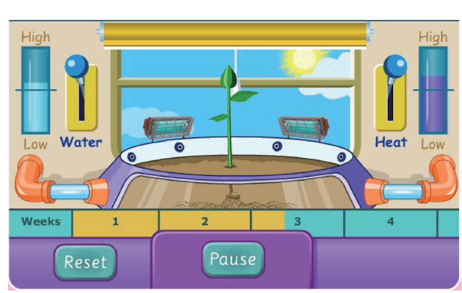

Figure 4 Melting Points Game[57].

There is moderate proof that simulations increase students' enthusiasm for science and science learning and less assurance about bolstering other science learning objectives. Evidence for the adequacy of games for supporting science learning is developing; however, as of now, it is uncertain. Until this time, the examination base is restricted[68,72]. Holly et al. conducted a user study for over six years to find the challenges and expectations of VR platforms in science education[73]. As a test example, they use a maroon platform that is a VR platform for teaching science subjects like physics. The study provides a gold standard for developing future VR and AR-based platforms for science education. As serious games are getting more influential, there is a trend in other fields of science of adopting and improving teaching education through games. A research paper by Ovecky et al. [74] discussed how serious gaming had improved science education, and now they look forward to bringing a similar impact on mathematical education. They developed a computer game[75] to help improve the players' logical thinking and declared that they were now ready to test the game in primary schools. Like [75], there are a lot of games that help children learn about math.

For example, Canoe puppy, shown in Figure 5, allows children to solve simple math problems. When a question is solved, their team paddles away to win the race in the water, as illustrated in Figure 5. These developments[76,77] and activities have forever transformed the nature and organization of life, including human, non-human, and the way we educate our youngers and kids. Furthermore, it is believed that the use of such games will strengthen student inspiration[40,46], encourage knowledge acquisition[47,69], boost task involvement[78], and nurture specific skills such as problem-solving and cooperation[71,79] by correctly envisioning abstract ideas and fundamental precepts of particular topics in the gaming environment. Researchers in studies like[46,80,81] have used some popular video games as models to explain that non-learning entertainment-oriented games can be effective for learning activities given the right circumstances.

3 Augmented reality in serious games

AR is a new IT feature that can present virtual objects or digital information in the real world. AR can also be considered as a bridge between the real world and the virtual digital one[82]. The Reality-virtuality continuum[83] accurately describes the relationship between the real world and the virtual one (Figure 6). In this regard, we discussed the benefits of two simulation games like "Force and Motion" and "State Change of Water" to analyze how successful simulation games are and whether they are worth being implemented in AR. A specific AR game named "AR-SEE" [46] is an example of the real application of AR games in Physics. Force and Motion is a PC game that teaches students to learn some laws of nature like gravity, friction, magnetic forces. Figure 7 shows how the concepts are implemented in the game environment[69]. The game was developed in Unity, where typing script describes objects and positions.

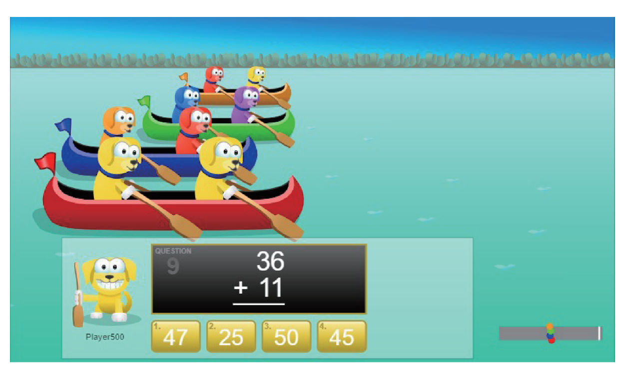

Figure 5 Canoe puppies[72].

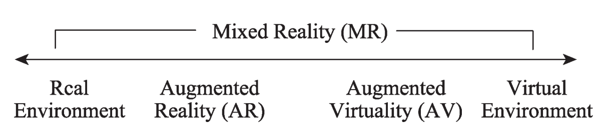

Figure 6 Reality-virtuality continuum[83].

Similarly, an AR-based game named "State Change of Water" (Figure 8) is a mobile game where the students can control water flow to save as much water as possible until the final place is

Figure 7 "Force and Motion." (a) The game lobbies. (b) Stage selection. (c) The first stage for the quiz. (d) The second stage for learning the frictional and gravitational forces. (e) The third stage is for understanding the magnetic forces[54].

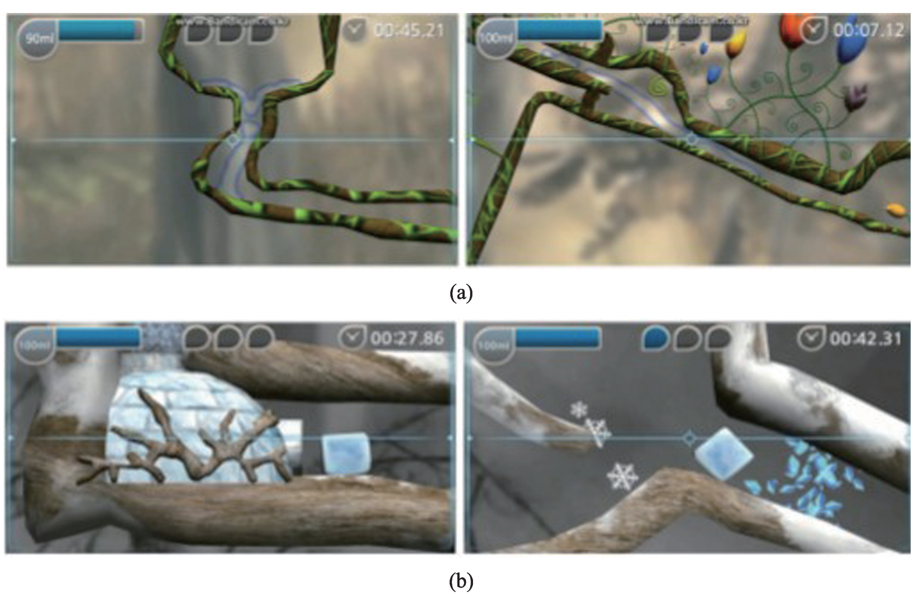

Figure 8 "State Change of Water." (a) Water. (b) Ice.[46]

reached. Furthermore, a game named "Augmented Reality Solar Energy Education (AR-SEE)" teaches solar energy education. The graphical depiction of the AR-SEE Desktop version can be seen in Figure 9. The game's mobile version is also available, and the API is illustrated in Figure 10. Vicente et al.[54] and Milgram[83] proved that the learning effects and motivation of the AR version are higher than the Desktop version of the game.

Figure 9 "Solar Energy Education game on desktop app without AR."[46]

Figure 10 "Augmented Reality Solar Energy Education (AR-SEE) game on the mobile app."[54]

It is also widely believed that simulation-based AR games in science and particularly Physic education can improve learners' motivation and learning effects since Physics is the science of nature. We need to imagine a lot of processes in nature to understand how nature works. It is also believed AR is a good enhancement for simulation-based games in Physics[82-85].

4 Methods

The study conducted a systematic literature review of the research on science education about serious gaming. To see if the use of serious gaming has grown over the years and if science education's learning experience is improved. To do so, first, we laid out the research questions, search keywords, and inclusion and exclusion criteria for our research. The papers selected for review in this study were from 2011 to 2021. Only published research papers and articles were considered for this review. (Springer database is searched from 2016 to 2021.).

The content was looked up using IEEE explore, Springer, and Scopus libraries. The following keywords were used to search science education content; ('science education' OR 'education science') AND ('serious games OR 'gamification') in Title or Abstract. We searched the exact keywords in the indexing terms of the paper, but we received lots of irrelevant articles. So, we decided to narrow it down to just Title and Abstract.

4.1 Inclusion & exclusion criteria

The title, abstract, and conclusion were reviewed. It was confirmed from the abstracts that the papers use serious gaming or science education as their primary discussion. Articles were excluded based on the following criteria:

- Studies related to serious games but not focused on science education.
- Studies related to science education but without using serious games.
- Studies are not offered in English.
- Studies are not available in full text.
- Preview only content.
- Literature review studies.

4.2 Results Overview

The results concerning libraries are as follows. We reviewed a total of ninety-two papers and found fortytwo relevant. We started by defining the research questions; we then restricted our research strategy. At that stage, we selected the databases and defined the search strings. After getting results from three databases using our search string, we did an initial analysis of the papers. In the next step, we applied the inclusion-exclusion criteria to find the relevant articles as shown in Table 3. After getting relevant articles, we analyzed them and created an excel sheet based on the results.

Table 3 The complete research approach from start to finish

Database	Initial search results	Relevant articles	Year
IEEE explore	26	14	2011—2021
Scopus	26	11	2011—2020
Springer	40	17	2016—2021
Total	92	42	—

4.3 Research methods in related studies

We identified what research methods are used in papers generally and how their results were found. How many conducted research studies were quantitative, qualitative, and based on a systematic literature review? What was the number of participants in the research, and how were the tasks classified? The methods were defined in five different dimensions. These dimensions were gaming, gamification elements, immersive setup, teaching, research. In the gaming dimension, the roles and categories of the games were examined. The different types of games used are role-playing games, puzzle games, strategy games, simulation games, action games, and fighting games. The games were also categorized according to their designs to see how many multiplayer or single players. They were further ordered to see which skill or learning outcome was expected of each game.

Then, gamification elements were highlighted, directly connecting with the motivation and interest of a participant towards a serious game. These elements were classified into challenges, rewards, and prizes. Further bonuses include achievements, and ranking while prizes consist of points, badges, and levels. Thirdly, the immersiveness of a game setup that brings life in the game and keeps the user's attachment with the games was reviewed, which includes various levels of immersive environments such as simple screen-based video games, VR, AR, and Mixed Reality (MR) based setup for participants. Further, it is found that most of the recent works used VR, AR, and MR-based setups for serious games. Fourth comes the teaching dimension, which focuses on examining the teaching concerns. The results for this dimension were categorized according to subjects taught in the games. Then, gamification elements were highlighted, directly connecting with the motivation and interest of a participant towards a serious game. These elements were classified into challenges, rewards, and prizes. Further bonuses include achievements, and ranking while prizes consist of points, badges, and levels. Then comes the teaching dimension, which focuses on examining the teaching concerns. The results for this dimension were categorized according to subjects taught in the games. In this case, the selected topics were physics, chemistry, biology, and earth science. Other categories were made according to the theoretical foundation of games; the classes involved were constructivism, cognitive theories, Vygotsky's theories, situated learning theory, activity theory, and activism. This dimension also had the games categorized according to the instructional strategy used. Collaborative learning, inquiry-based learning, problem-solving, learning by designing, prediction-observation-explanation (POE), and self-explanation were the categories used for this strategy.

Finally, the methods of the research dimension were explained and how the results were categorized according to this dimension. Firstly, the participants were classified according to their academic levels: pre-school, elementary school, junior high school, senior high school, and university or college. Secondly, the categories were made according to the research methods used. Quantitative research where only quantitative research methods were used, qualitative research where only qualitative research methods were used, and mixed research where both quantitative and qualitative research methods were used.

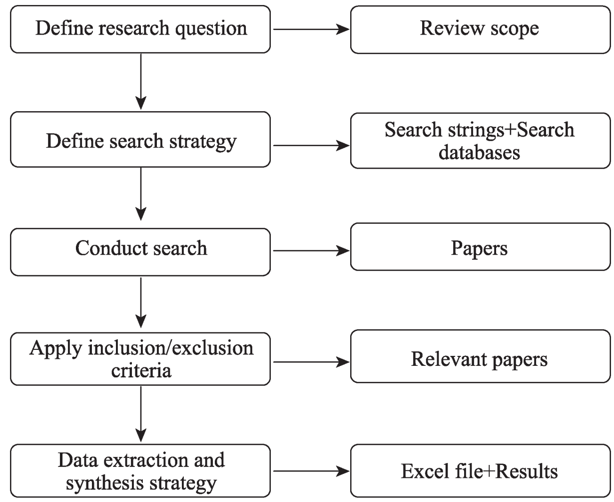

Figure 11 Complete method for systematic mapping.

5 Results

This section will discuss the results extracted from the literature mapping. We will answer each of the research questions written in the Introduction, such as the significant contributing journals, year distribution of the articles, country-wise distribution, and main evaluation methods. In addition to that, we will briefly discuss the results from relevant studies and the study related to AR or simulation-based games in teaching science subjects. Furthermore, we will talk about the positive and negative aspects of serious games in science education. Last but not least, we will briefly write about the public or learners' attitudes towards the use of serious games in education.

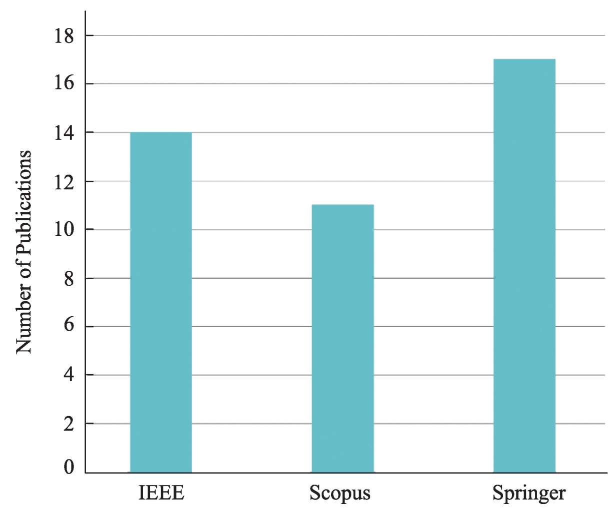

Figure 12 Number of publications concerning journal. With springer having the maximum number of seventeen publications.

5.1 Number of studies published and major contribution journals

In Figure 12, the number of studies about the use of serious games in science education published from 2011 to 2021 is given. Springer has the maximum number of studies published, which is seventeen. Whereas IEEE and Scopus have fourteen and eleven, respectively.

5.2 Year distribution of the articles

Figure 13 shows the number of studies concerning years. As per the results, 2016 stood out to be the most active year in research regarding the use of serious games in science education, with a total number of twenty-one. In 2012, 2013, and 2018, four studies were carried out each year.

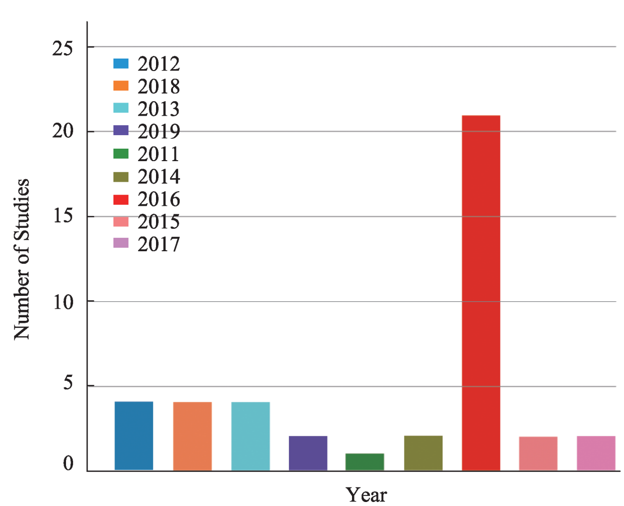

Figure 13 Number of studies with respect to the year. Twenty-one publications in the year 2016.

5.3 Country-wise distribution

The results of the country-wise distribution of studies are shown in Figure 14. Studies and research work are carried out in a total of twenty-three countries worldwide. The leading number of studies, ten, are carried out in the United States. Whereas the second largest number of studies are carried out in the Netherlands. It can also be seen that a major portion of studies is done in developed countries such as the United States and a lot of European countries, and a very small number of research is being done in developing countries. As per the results, there is not even single research that has been done on serious games in science education in south-eastern countries like Pakistan, India, and Bangladesh.

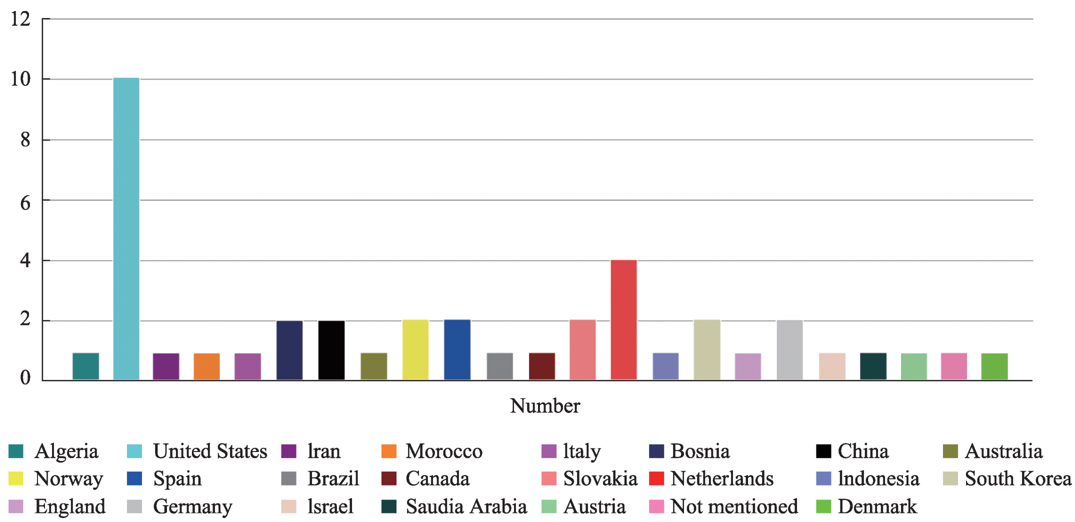

Figure 14 Country-wise distribution. The research was carried out in twenty-three countries around the world with the United States having the leading number ten. In most of the countries, only one research/study was done.

5.4 Evaluation methods

Figure 15 shows the number of studies using different evaluation methods such as Observation, Questionnaire, and Interviews. It can be seen that the leading method of evaluation in these studies was observation used in twenty-two studies. Eleven studies used Interviews as a method of evaluation. Last but not the least, nine studies used Questionnaires as a method of evaluation.

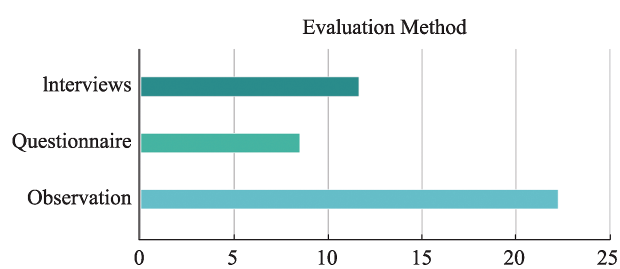

Figure 15 Evaluation method(s): questionnaire, interviews, observation.

5.5 Summary of results in the relevant studies

The results found were recorded according to every dimension and each category. It was found out that adventure and simulation games have played a major role in contributing to science learning in the form of serious games whereas fighting and action games need to do better. It was also discovered that almost 65% of the games were single-player, while others were multiplayer. In the teaching dimension, it was found that physics and biology are the most taught subjects through serious games whereas not a single game was found for chemistry. Coming down to instructional strategies more games were found out about teaching problem-solving skills and collaborative learning whereas very few games are there to teach self-explanation. For the research dimension, the results are according to academic levels. It was discovered that most of the games are for elementary students and junior high school students. Then comes the senior high school and college for most games made and finally the pre-school. Further categorization was according to research methods. Most of the research conducted was quantitative, then on the second it was a mixed-research method, and third was the qualitative research method with the least number of research.

It was also found out that science education is the most used topic for serious games; research showed there are hardly any math games for learning. Science education games were reviewed to determine the methods and approaches used for game development and how they can be improvised to create a math game. If there is research conducted of this sort, we can say that science education has come a long way in collaboration with serious games that it is now inspiring researchers of other fields to learn and improve from it. Dating back to 2002 when there was hardly any research done for science education in serious gaming to 2018, when it is inspiring other fields to get involved with serious games for an advanced form of learning, we can say that it has come a long way over these two decades. The evolution of science education and its teaching methods over the years has caused many improvements in learning science. People find it easy to grasp science knowledge, and by learning to use it in practical ways, they find it easy to benefit from these methods learned when applying them to real-life situations. Now that science education is more useful, it is now more effective in people's lives.

5.6 Results for simulation-based serious games in physics

"Force and Motion" and "State Change of Water" were evaluated using the method proposed by Jung et al.[80]. In Table 4, elements of evaluation by teachers and the corresponding scores given by schoolteachers are listed. The number of teachers involved is accordingly seven teachers in "The Rift of Dwarves," six in "The Gold Mine of the Owl King," eight in "The Orange Mountain Range," and four in "State Change of Water." Firstly, in the category of teaching-learning strategy, "The Rift of Dwarves," "The Gold Mine of the Owl King," and "The Orange Mountain Range" got scores higher than "State Change of Water." The scenarios of all games were commented as good by teachers, but they mentioned terrible music, a low point gaining system, challenging levels. The screen organization was evaluated below 2.5. Most probably, this was due to the bad quality of graphics. But this needs to be understood as the most common weakness of prototypes. The economics-morality element got a high score. Mainly because it was available for free and easily downloadable. But also, from a survey, elementary school teachers mentioned that animations are much more appropriate for them, and work needs to be done. Generally, according to [47], teachers evaluated games to be low in teaching-learning content and rewarding system and needs improvement about animations since it is for elementary school students, but the technology was evaluated positively. A summary of these statistics can be seen in Figure 16.

Table 4 Elements of evaluation[47]

Evaluation elements	Meaning
Teaching-learning contents	Validity of purpose, the validity of contents, The practicality of contents, reliability of contents, systematicity of contents, appropriacy of quantity
Teaching-learning strategy	Motivation, learner control, feedback, consideration of learner level, System to help in learning.
Screen organization	Appropriacy of design, the freshness of design, convenience of design
Technology	Systematicity of management, security
Economics morality	Copyright protection, human rights protection, personal information protection, economics

AR-SEE game and its desktop version were tested by thirty-six graduate and undergraduate computer science students, starting from 20 until 30 years old. Tests were conducted in three categories: Usability, Learning Effects, and Motivation. They used the Kruskal-Wallis test, Wilcoxon Signed-Rank test, Spearman Rank correlation test. The results persuaded researchers that despite decreased usability, AR serious games can enhance motivation to learn.

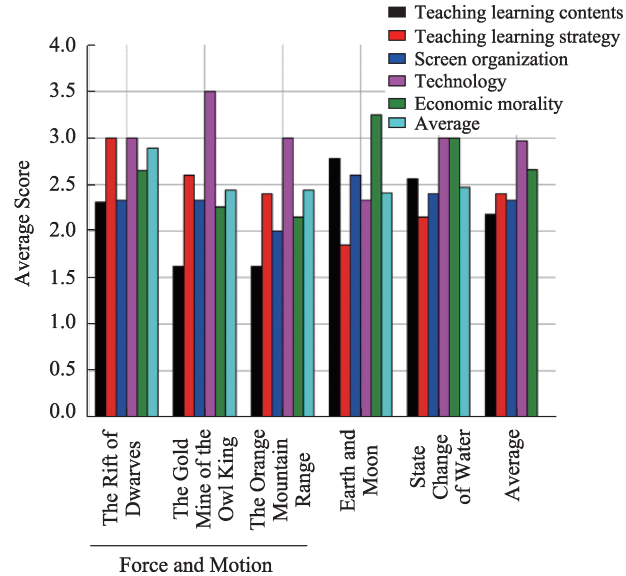

Figure 16 Evaluation's result using "Force and Motion" and "State Change of Water."

5.7 Positive aspect about the use of serious games in science education

There are many conclusions in serious game-assisted education, which are mostly supportive, coupled with a few bad outcomes. Serious gaming-infused learning will make it easier for learners to understand science comprehensively because of increased science efficiency and the continued maintenance of science information. Game immersion has also been favorably associated with the success of science literacy[86,87]. Furthermore, in both serious gaming and non-game-assisted learning methods, no major discrepancies in undesired factors (e.g., grievances or disruptions influencing the gameplay environment of other players) have been reported between teachers and learners[88]. Serious games are effective in improving cognitive ability and power, as well as fun mood, in generalized learning. They have been observed to help learners develop cognitive abilities and increase the positive effect of learning[89,90]. Serious games also helped pedagogy to offer open learning for various learners who could step beyond the boundaries of conventional learning[84,91]. Game-based learning has also been shown to be effective in socio-cultural learning in contexts of cognitive and uplifting effects. Given the fact that the vast majority of studies favorably assessed the impact of serious games on learning, human interactions, and social communication, negative outcomes could not be overlooked[92].

5.8 Negative aspects about the use of serious games in science education

Some studies also found a few negative results, especially in terms of the correlations between mental workload and learning effect. According to research, the nature of serious games negatively influenced the relationship between mental workload and learning effect[93]. In the case that a difficult game makes the intellectual workload heavy, the playing result seems to be adversely affected and vice versa. This is also no surprise that, in the serious game" Peacemaker" (Impact Games 2007), there were no major gaps in in-depth learning between learners[2]. This form of serious game may have exacerbated the cognitive workload and thus reduced learning performance, as the mental workload, such as the increase in heart rate, has dramatically suggested learning outcomes at a certain level of difficulty[89].

5.9 Attitudes towards the use of serious games in education in general

Developing perceptions towards serious game design using sophisticated computer technology has been recognized as a crucial factor in using and adopting information technology[94]. Understanding learners' attitude towards serious game-assisted learning is essential for scholars to develop effective teaching outlines to satisfy the various needs of learners and for practitioners to create sound, realistic games to promote learning performance. Different attitudes reflect the specific needs of learners and professionals, on which developers and teachers of serious games can base their theoretical and realistic structure[95]. Serious games can enable learners to maintain positive attitudes towards academic tasks with good self-regulation if they are immersed in a gaming situation. Optimistic attitudes allow learners to gain more success than pessimistic attitudes. Therefore, it is fair to assume that serious gaming leads to far more constructive behaviors than conventional schooling. Serious games mounted on iPhone, iPods, or other handheld devices may be used for mobile gaming. Unlike traditional classroom-based learning, virtual learning is not limited to set classrooms. Learners continue to be drawn by their versatility and ease. Students typically have positive attitudes towards this enticing learning strategy, which quickly sparks their curiosity and inspiration[96]. To promote positive attitudes towards serious game-assisted learning, close attention should be given to how serious games are created[97].

6 Conclusion

This paper concluded that a decent amount of research is being carried out on serious games, and there is a steady increase. Still, at the same time, this vast field has enormous room for further development and improvement. Nevertheless, it is in a very early phase, and the progress needs to pace up compared to technological advancements made each year. Especially in developing countries, more attention is required to create and use serious games in science education institutions. In the years to come, the trend shows that serious gaming will be used in both scientific and non-scientific subjects and improve the learning experience for students. The deployment of serious games to such a extend and achieving a high-efficiency level will be challenging and crucial in the coming years. Furthermore, results of evaluation by teachers on "Force and Motion" and "State Change of Water" are considered positive, as technology improved motivation and learning effects among elementary schools' students. At the same time, it also has some limitations. Most of the teachers agree on the advantages of serious games using simulations in science subjects. Simulations are the core of any AR game in science subjects. In the second test using AR-SEE and its desktop version, after results of usability tests, learning effects, and motivation, AR games showed less usability but very high interest to learn about passive solar energy by university students proving the benefits of AR. In Table 5, it is evident that technology made a positive change for user motivation to learn Physics. During the review of papers and evaluation numbers, we felt more confident about the advantages of simulation-based AR games in science subjects.

Table 5 Results of evaluation of "Force and Motion" and "State change of water"[47]

2*Games		Average scores					2*Average
		Teaching learning contents	Teaching learning strategy	Screen organization	Technology	Economic-morality	
3*Force and Motion	The Rift of Dwarves	2.31	3.00	2.33	3.00	2.65	2.89
	The Gold Mine of the Owl King	1.62	2.60	2.33	3.50	2.26	2.44
	The Orange Mountain Range	1.62	2.40	2.00	3.00	2.15	2.44
Earth and Moon		2.78	1.85	2.60	2.33	3.25	2.41
State Change of Water		2.56	2.15	2.40	3.00	3.00	2.47
Average		2.18	2.40	2.33	2.97	2.66	

7 Trends and future work

A systematic literature review was done at the Beijing Language and Culture University in 2019 to find out the trends of publications related to the use of serious games in education (not science education). As shown in Figure 17, the year 2009 began to witness publications about serious game-assisted education. With time, the number of publications steadily rose until its peak in 2017. The year 2018 also predicts many publications since the data were obtained in September 2018. Far more articles may be waiting to be published and indexed in "Web of Science." The reasons for the increasing number of publications should be explored, among which influencing factors in serious games-assisted education should be first discussed[98]. Even though all the evaluations are done qualitatively, we still cannot answer many questions, such as what if there was human bias? What if Simulation-based AR games are not good enough for other fields of Physics like Optics or Colour? What if surveyors were felt interested in AR because they had never tried it before? What if users' motivation is not stable? Meaning after continuous playing, they do not engage in the game. Evaluations probably need to be done in a more extended time range. There is a question of "how generalized are the results?". To answer that question, more detailed questions need to be answered, and if existing products would be personalized to people, maybe other evaluation methods and a different audience is required.

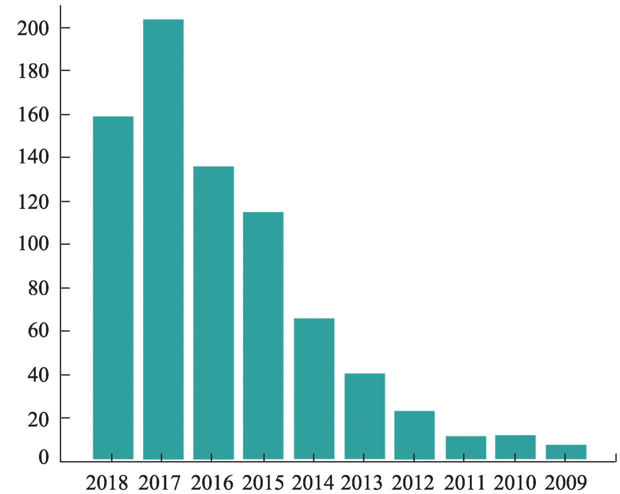

Figure 17 A histogram of related publications ranging from 2009 to 2018.

Declaration of competing interest

We declare that we have no conflict of interest.

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